Successful Utilization of CO_2 Embedded in Concrete

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Miracon®, LLC, based in Richardson, Texas, has developed the first successful technology to embed CO_2 throughout concrete at the mixing stage without modifying the sequencing process.

This process has potential to enhance the final properties of the concrete with no negative effects.

The technology utilizes a cell to capture and manage the CO_2, hence defining CAPCELL®. CAPCELL® is a barrier that prevents CO_2 from reacting with water and calcium hydroxide when it is mixed throughout the concrete paste or wet stage. The CO_2 is time released in a controlled manner to react with the calcium hydroxide which permanently removes CO_2 from the environment through a chemical reaction.

Cement, and therefore concrete, is a natural sink for CO_2. Therefore, the CO_2 is not only CAPCELL®-ized and locked in, but also engages in the chemistry and becomes a permanent part of the final product. As the CO_2 is released in a controlled, timely manner, it immediately converts to calcium carbonate, and has the potential to enhance the final properties of the concrete with no negative effects.

CAPCELL® CO_2 embedment can be implemented immediately, globally, in all markets, for all applications of wet cast concrete as existing sequencing and processes do not have to be adjusted. The biggest opportunity globally is utilization of CO_2 enhanced concrete for infrastructure: bridges and roadways. Utilization of CAPCELL® is available for cast-in-place (poured) precast and on-the-job. This ranks as a disruptive technology to control CO_2 embedment in concrete without requiring change in infrastructure.

CAPCELL® utilizes concrete as the mechanism for implementation. At 3 tons per person per year, concrete is the number one used building material in the world and the second most consumed product next to water. Concrete has a low-carbon footprint per pound relative to other industrial products, however, the size of the industry nets the largest opportunity currently available for immediate reduction of Greenhouse gases. Good concrete design, particularly in freeze/thaw climates, dictates an average use of 6% void space (gas entrainment) for the sustainable life of concrete infrastructure. Fifty miles of highway would consume over 185 tons of CO_2 utilizing CAPCELL® Technology.

The major component of Greenhouse gas (GHG) is CO_2 which comprises on average 80% of the GHG's, which for the past six hundred thousand years or so, have remained below 300 parts per million (ppm).[1] Technological advancements as well as global population growth patterns in the past 200 years have driven GHG's to 335 ppm in 1980, and an astounding 406 ppm as recorded by www.CO2.earth in June of 2016. Scientists indicate that a balanced ecosystem, requires a level less than 450 ppm, which correlates to net temperature change of 2^0C. A temperature change greater than 2^0C challenges our norm of existence as we know it today. [2]

The concrete and cement industry in 2014 was responsible for roughly 7-8% or 2.5 billion tons (bt) of the Greenhouse gas emissions. The United States has proposed Greenhouse gas (GHG) reduction targets "in the range" of 17 percent by 2020 and 26 – 28 percent by 2025 [3]. These reductions in Greenhouse gases must be in place by 2030 as per The International Energy Agency for sustainability of our planet. In addition, the advancement of the middle class in areas such as China and India impose an additional demand for concrete and other cementitious products. CAPCELL® enables a significant and quantitative reduction of carbon dioxide (CO_2) in our earth's atmosphere, thus lowering Greenhouse gases.

The Concrete Industry Today

Concrete applications are as numerous and diverse as restaurants within a large city. They range from infrastructure, such as roads and bridges, to precast buildings, components for housing, playgrounds, chemical plants and soil stabilization applications. Much of the industry is fragmented and not regulated. The Infrastructure segment, such as roads and bridges, in the United States comprise over 50% of the concrete usage today. This infrastructure segment is typically regulated and, therefore highly influenced by several governing bodies including ACI, ASTM, state government agencies (e.g. city, state and Federal D.O.T.'s, Tollway authorities) as well as the Federal Highway Administration (FHWA). These agencies look to set requirements that have inherent safety considerations for placement and utilization of concrete for infrastructure purposes. These agencies, when engaged, look to specify and monitor concrete's key properties such as strength (compressive and flexural) and sustainability (durability).

Utilizing good science and tested mix designs enables the industry to satisfy the above key properties and reduce the use of carbon footprint products such as cement thereby reducing the Greenhouse gases and CO_2 emissions.

Utilization of CO_2 in Concrete

CO_2 can potentially have a significant positive impact on the above mentioned key design properties of strength and sustainability. However, as current best-practice know-how stands today, when CO_2 is introduced into normal wet cast concrete manufacturing/ mixing process, rapid adsorption of CO_2 causes development of carbonic acid and excess heat which can lead to flash setting and less than optimal properties for the final concrete including reduced life span. An alternative approach to introducing CO_2 into wet cast concrete is now available via CAPCELL® technology which embeds CO_2 as it is introduced into wet/plastic concrete. This process does not interfere with any of the desirable wet/plastic stage properties, such as slump/flow, since the release of the CO_2 occurs after the concrete is placed.

Production of cement, a primary constituent of concrete, utilizes a process where products such as limestone and sand are heated to 1450˚C. Upon cooling, this material is then ground, and gypsum is added to control the rate of (concrete) setting. This deliberate process generates CO_2 in the following manner:

- CO_2 is released when the limestone is heated
- CO_2 is generated by burning fossil fuels to heat the kiln
- CO_2 is also generated to create the electricity in the production process and direct fuel consumed for transportation and hauling of materials.

Based on the above, there are five areas of opportunity to reduce CO_2 production in the concrete industry:

1. Reduction in the use of Portland Cement and allowing for optimized use of Supplementary Cementitious Materials. (SCM's)

2. Removing and then recycling and consuming CO_2 in everyday concrete as well as high performance concrete
3. ***Reduction of the use of limestone or similar products that break down and release CO_2
4. ***Reduction of fossil based fuels to drive the kiln
5. ***Reduction of transport of materials

   ***Items 3-5 have significant opportunities but are outside the scope and direction of this paper. Therefore, we will focus on 1 & 2.

Polymer based air entrainment systems (PBAES)

CAPCELL® is designed to enable the use of existing mix designs, products and infrastructure. Current and historical use of CO_2 enhanced concrete requires a significant cost increase due to the requirement of special concrete mixing/manufacturing chambers and/or special curing chambers and/or certain types of precast concrete. CAPCELL® enables all wet cast applications
– precast and transit mix - to be cast in place. Therefore, highways and bridges can now utilize CO_2 enhanced concrete without any modifications to the sequencing or mixing process. This immediately results in lower impact on the environment.

Use of Polymer Based Air Entrainment Systems (PBAES) versus Surfactant Based Air Entrainment Systems (SBAES) enables a controlled, deliverable end-product with a designed amount of air or gas. This systematic approach enables concrete quality to be more predictable, and assuredly provides the pathway to a more sustainable end-product.

Typically designed and executed concrete mixes are quite appropriate for the embedment of CO_2 which directly correlates to reducing the CO_2 released into the atmosphere. Unlike other air entraining products (SBAES), CAPCELL® allows for SCM's to be used in higher replacement (for Portland Cement) quantities. The net effect of this can be lower Portland Cement, which impacts and lowers the carbon footprint of concrete. In addition, CAPCELL® is not impacted like SBAES's as they relate to use of fly ash as a replacement for Portland Cement in the blend. Therefore, the net amount of cementitious material remains the same since the volume of fly ash is optimized, the Portland Cement content can easily be lowered.

Examples: For the purposes of consistency, all calculations will utilize the following:

- A Cubic yard (yd^3) of concrete is 27 cubic feet (ft^3)
- CO_2 at Standard Temperature and Pressure (STP) weighs 0.123 lbs. / ft^3
- CO_2 CAPCELL®-ized weighs 0.456 lbs / ft^3
- A cubic yard of concrete with 6% gas (CO_2) entrainment weighs approximately 3800 lbs.
- Standard blend will use 400 lbs of Portland Cement per yd^3 of concrete
- USA cement usage for 2013 was 77 million metric tons
- Worldwide cement usage for 2013 was 4080 million metric tons

CO_2 Embedment in High Strength Applications

Infrastructure design criteria normally dictates at least 6% air / gas entrainment.

At 6% gas entrainment:

Total gas = 27 ft^3 * 6%

Total gas =1.62 ft^3

Weight of CO_2 per cubic yard of concrete

Weight of CO_2 = 1.62 ft^3 * 0.456 lbs. / ft^3

Weight of CO_2 = 0.46 lb/ft3

One lane-mile of highway

- 1 lane, 12 feet wide per lane, 10 ft wide shoulder on the outside, 4 ft shoulder on the inside, 8 inch thick concrete, 5280 ft/mile

Concrete Volume per mile per lane

= [4 lanes *12 ft/lane) + (2 shoulder * (10+4) ft / shoulder set)] * (5280 ft / mile * 50 miles) * (8 inches thick /12inches/ft)

Concrete Volume per 50 miles = [48 ft+28 ft] * [5280 * 50] * 8/12

Concrete Volume per mile = 13,376,000 ft^3

CO_2 utilizing 0.46 lb / ft3 of concrete assuming 6% entrainment

=13,376.000 * 6% * 0.46

= 369,178 lb of CO_2 consumed for 50 miles of highway

= 185 Tons

Applications Using 35% to 70% Gas Entrainment

Several applications currently exist that are ideal for utilizing 35% to 70% gas entrainment. One example is Controlled Low Strength Material (CLSM) or commonly known as Flowable Fill / Soil Stabilization. A second example is Fire Retardant and Insulating for high risk chemical plants. Ultralight concrete is often used to cover building structural beams in commercial construction where very low thermal conductivity is a must. Utilizing CAPCELL® with a CO_2 embedment level of 35% yields the following:

35% CO_2 Embedment of Structural Beam

Volume of Concrete for one W 21*62 *** beam with a cross sectional area of 18.3 in2, dimensions of 8.24" * 21" * 20 ft steel I-Beam coated with 4" of fireproofing concrete

in^3 concrete = {[(16.24") * (29"] – [2 * (12.2" * 4")]- 18.3 in^2} * (20 ft*12"/ft)

= {(471) – [98]- 18.3} * 240"

= 85,358 in^3

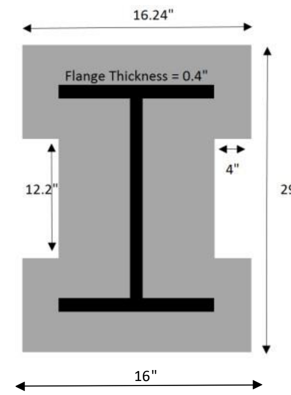
ft^3 of Concrete= 49.4 ft^3

Vol. of CO_2 = 49.4 ft^3 concrete * 35% CO_2

= 17.3 ft^3 CO_2

Weight of CO_2 = 17.3 ft^3 * .46 lbs. / ft^3

= 7.9 lbs. CO_2 per beam



***http://www.engineeringtoolbox.com/american-wide-flange-steel-beams-d_1319.html

United States Annually (6% Gas Entrainment)

77 mT 10 year average cement consumption (mT - millions of metric tons - Tonnes) (PCA)

1.6 ft^3/yd^3 amount of CO_2 consumed at 6% per yd^3 of concrete (common for high strength concrete application - see above)

Cubic Yards of Concrete used each year in the United States yd^3 concrete = (77 mT * 1,000,000 tons/mT * 2200 lb./ton) ÷ 400 lb./ yd^3

= 423.5 million yd^3 Concrete used

Therefore, the potential to reduce the CO_2 / Greenhouse gases per year through consumption in concrete is:

Weight of CO_2 = 0.74 lbs. / yd^3 (from above)

Amount of CO_2 (tons) = 423.5 million yd^3 concrete * 0.74 lbs. / yd^3 ÷ 2000 lbs. / ton

= 156,695 tons of CO_2 per year

The potential reduction of Greenhouse gases by utilizing CO_2 embedment is

Over 265 thousand tons per year.

Global Use, Annually (6% Gas Entrainment)

The global use of cement is 53 times greater than that of the USA as per the National Ready Mix Concrete Association (NRMCA).

Therefore, the potential consumption of CO2 globally per year is:

= 156,695 tons * 53

= 8,304,835 tons

Using 6% for all gas entrainment is extremely conservative. Utilizing the Portland Cement Association average usage statistics for all concrete placed, including applications such as Controlled Low Strength Material (CLSM or Flowable Fill) and non-structural applications, yields a more accurate estimate to be:

= 14 million Tons of annual usage on a Global Scale.

It is likely no other single industry or application, can have this impact on Greenhouse gases, in the short term.

Testing of Cast in Place for CO_2 Embedded Concrete

Miracon® has completed third party testing of CAPCELL® technologies for characterization of the physical and mechanical properties of the fabricated concrete specimens. Detailed petrographic evaluation was utilized to assess the impact of embedded CO_2 as compared to the control mixture made with compressed atmospheric air.

Conclusively, no development of carbonic acid was found at any stage of the mixture evaluation as evidenced by petrographic analysis down to parts per billion (ppb).

Concrete Test Specimens:

Fractured Surfaces with application of Phenolphthalein

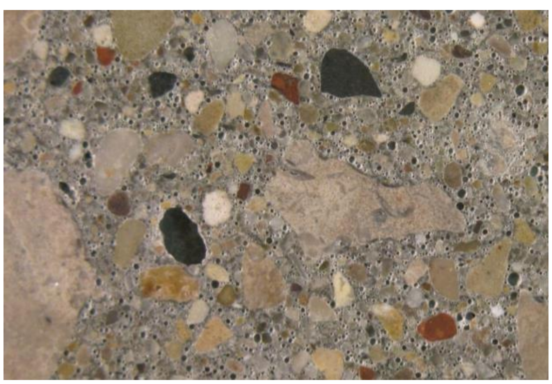
Surfaces that turn pink, indicate no carbonation. Surfaces that remain their existing color (grey) indicate carbonation. Indicates no carbonation in either specimen.

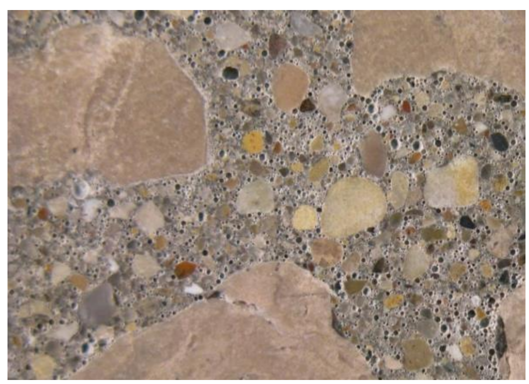
Specimen Prepared with Air Entrainment

Specimen Prepared with CO_2 Embedment

Microscopic Illustrations of Specimen Microstructure

Indicates no undesirable change in material properties

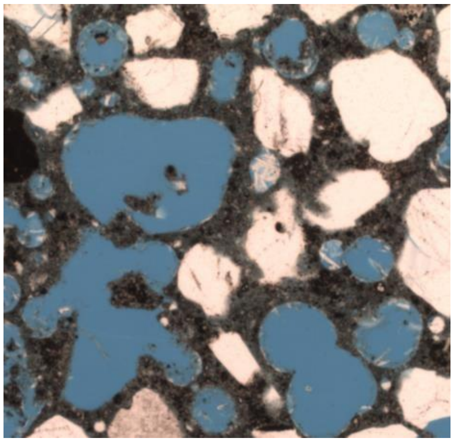


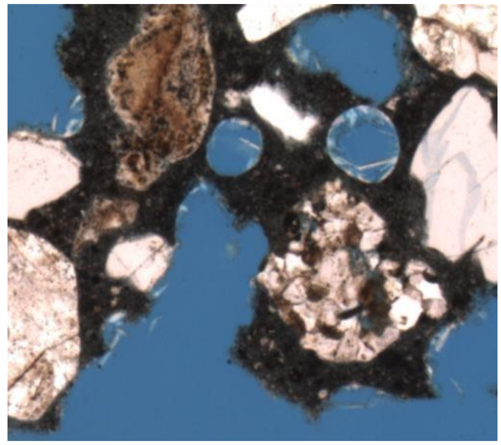


Specimen Prepared with Air Entrainment

Specimen Prepared with CO_2 Embedment **Extreme Resolution**

Shows no evidence of carbonic acid in either specimen





Specimen Prepared with Air Entrainment

Specimen Prepared with CO_2 Embedment

Conclusions from the Testing:

- With regard to freeze thaw resistance and length change test comparison, there was no noticeable difference between the evaluated physical properties of the concrete produced with embedded CO_2 and the concrete produced with compressed atmospheric air.
- Thorough petrographic examination results give a strong indication that CO_2 introduced into the concrete produced an ideal air void microstructure similar to the air entrainment test.
- Carbonation of the concrete paste was not observed on the macro- or micro scale in any of the investigated concrete mixtures.
- Importantly, the microcell bubble spacing in the hardened concrete specimens remained the same at 0,002 inches for both the embedded CO_2 and the compressed atmospheric air.

Opportunities Utilizing CAPCELL® Technologies with CO_2 Embedment

Today's infrastructure is poised for adoption of a new, disruptive technology to replace the aged and deteriorating roads and bridges. The ideal plan for the USA/world/industry would involve construction of new roads and bridges with long term, sustainable products and techniques that lower the environmental impact on our world – such as described in this paper.

As per Associated Press Sept 15, 2013:

> *“analysis of 607,380 bridges in the most recent federal National Bridge Inventory showed that 65,605 were classified as "structurally deficient" and 20,808 as "fracture critical." Of those, 7,795 were both — a combination of red flags that experts say indicate significant disrepair and similar risk of collapse. These bridges carry more than 29 million drivers per day. “*

CAPCELL® technology delivers/yields an optimized, sustainable, final product. Utilizing products, equipment and techniques that are already commercially viable, CAPCELL® is an enabling system that:

1. Reduces carbon footprint by reducing the volume of Portland Cement per volume of concrete using gas entrainment and SCM’s.
2. Reduces the carbon footprint by reducing the horsepower and manpower to mix and place concrete cast in place due to the thixotropic properties of the patented chemistry.
3. Increases the consistency of multi mix / multi truck blends for higher yield.
4. Increases sustainability due to its unique chemical properties, resulting in excellent bonding to rebar as well as other structural containment.
5. Engages in permanent, irreversible embedment of CO_2 using concrete as the ideal mechanism.
6. Replace current infrastructure technology with more sustainable, cast in place, lower GHG footprint concrete systems.

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